Short Course on Experimental Dynamic Substructuring

Module #1: Introduction

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Short Course Notes For:
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About the Instructors

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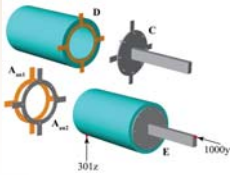
Outline / Schedule

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- 5:45 - **Mod09**: Closing Remarks
  - Papers of interest in IMAC 2016
- [Appendix] - **Mod10**: Hands on Exercise: Guitar - **Matt**

Informal Survey

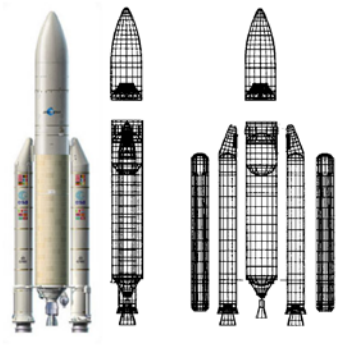
Have you:

- Had an undergraduate-level class on vibrations?
- Had a graduate-level class on vibrations?
- Had a graduate-level class on finite element analysis? Experience with FEA?
- Ever performed a modal test? Regularly?

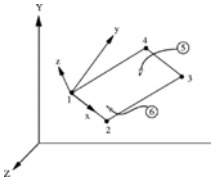
- Approach for this short course
  - 80% Lecture , 20% Guided exploration
  - Files needed for the examples can be obtained at:
    - http://substructure.engr.wisc.edu/ in the “Tutorials” section:
    - http://substructure.engr.wisc.edu/substwiki/index.php/Tutorials
- Assessment :
  - You will be asked to complete a short questionnaire within a few days of the short course to help the instructors to evaluate its effectiveness.

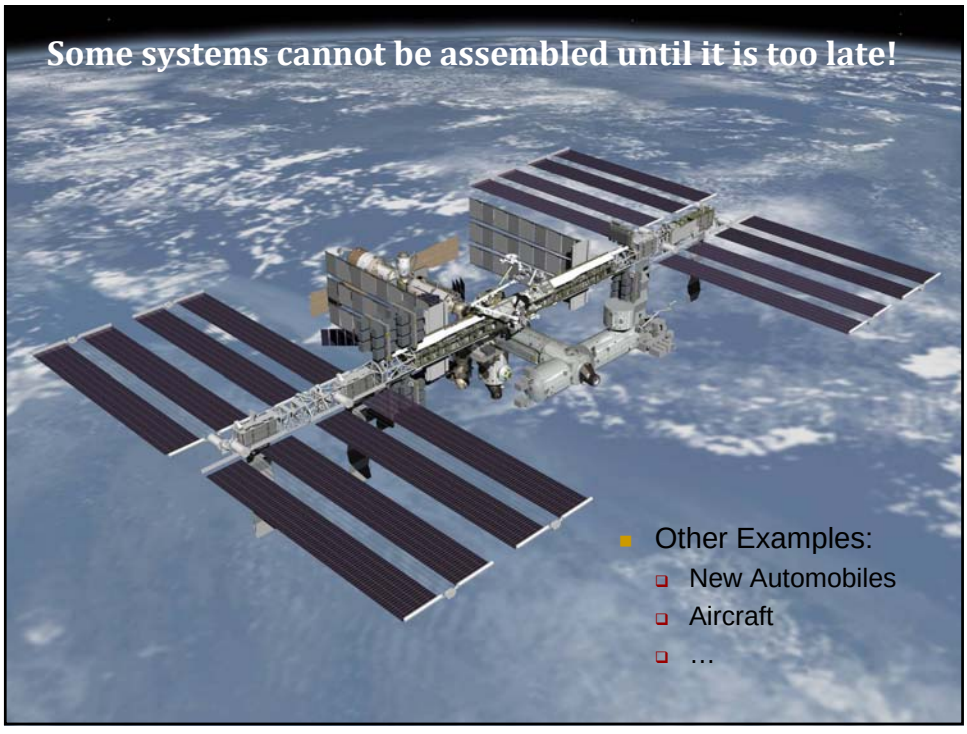
What is Substructuring?

- Substructuring is a process whereby individual components of a structure are analyzed or tested separately and then combined to predict the response of the built-up structure.
  - Reduced Order Modeling: create an approximation to a model to reduce the computational burden
- Analytical substructuring forms the basis of the Finite Element Method, and related techniques, such as the Craig-Bampton method, have been key components of structural analysis for over 40 years.
- **Experimental/Analytical Substructuring** is a far less common variant where a model for one or more subcomponents is derived experimentally.

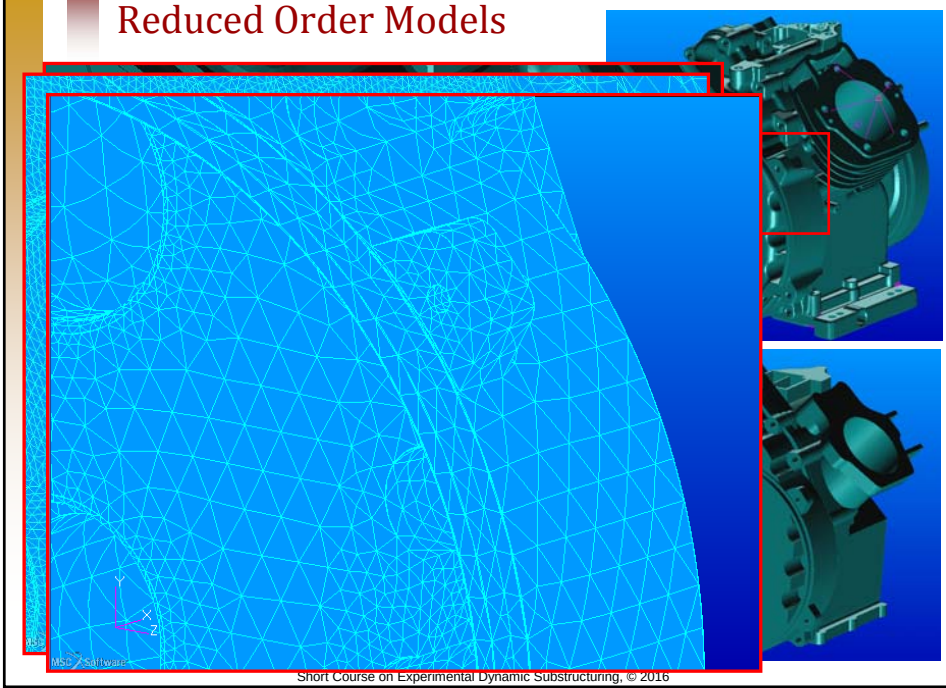


Ariane 5 Launch Vehicle (ESA) and diagram depicting potential substructures



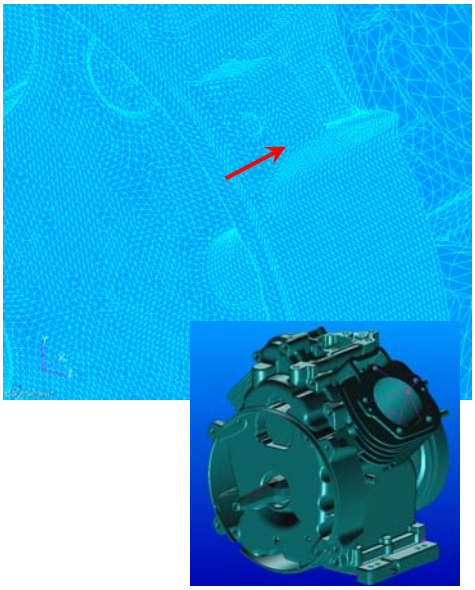


Reduced Order Models

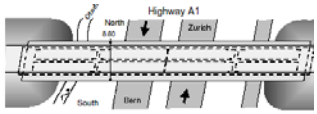


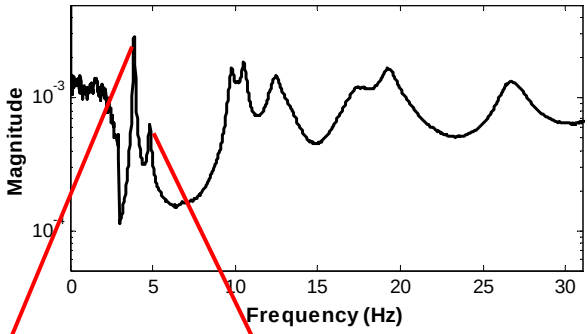
Basics of Substructuring / Reduced Order Modeling

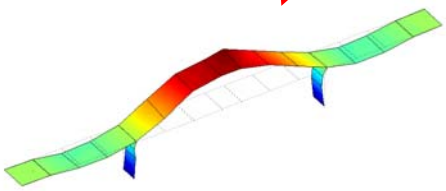
- A complete FEA model allows for arbitrary motion of any node of the structure.
- A substructure or reduced order model can be more efficient by capturing only those motions that are likely in the application of interest.
- This is especially relevant to structural dynamics, where the deformations observed are often the net effect of only a few vibration modes.

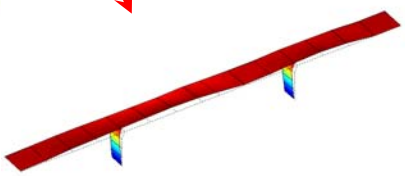


Example – Swiss Highway Bridge









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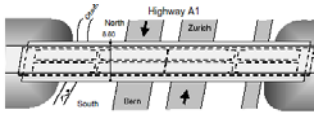
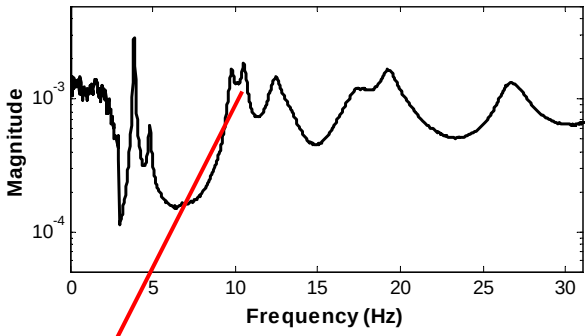
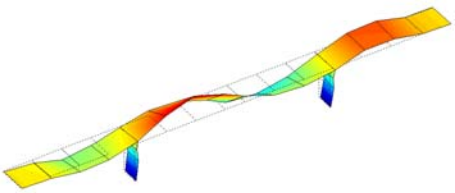
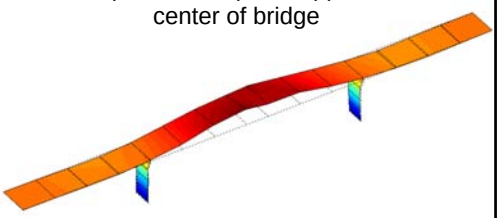




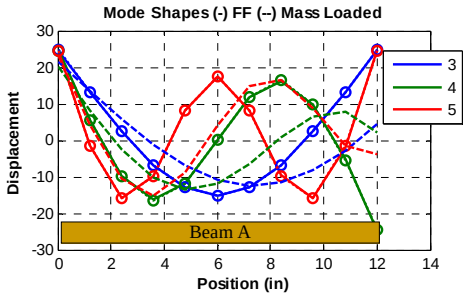
Response to impulse applied to center of bridge

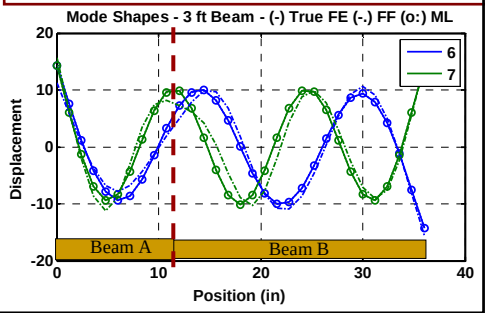




Modes as Basis Vectors: A Simple Example

	Nat. Freq (Hz)		Error (%)
Mode #	FEA	FF	E (%) FF
3	121.0	128.0	5.8%
4	333.3	364.0	9.2%
5	653.3	658.8	0.8%
6	1079.7	1130.8	4.7%
7	1612.4	1781.8	10.5%
8	2251.3	2282.0	1.4%
9	2996.3	3176.3	6.0%
10	3847.2	4396.0	14.3%
11	4803.7	4934.3	2.7%

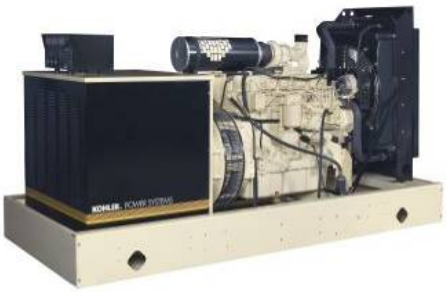


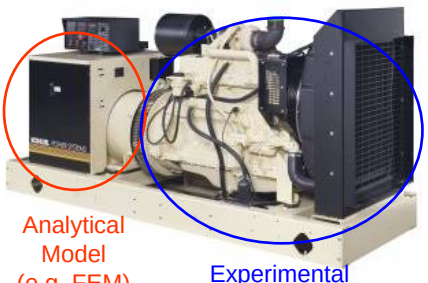


- Changing the modal basis from Free-Free modes to Mass Loaded modes reduces the errors dramatically!
- A reduction basis must be carefully selected to produce accurate results!

Experimental – Analytical Substructuring

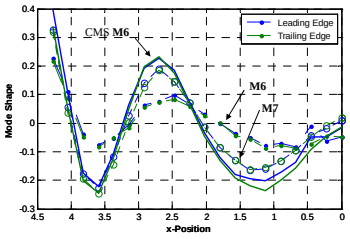
- Often we are tasked with analyzing systems where one or more components are very difficult to model analytically.
  - Intricate geometry
  - Drawings proprietary or unavailable
  - Unknown material properties
  - Bolted joints with complicated stick-slip behavior
  - …
- These components can potentially be replaced with an experimentally derived model.





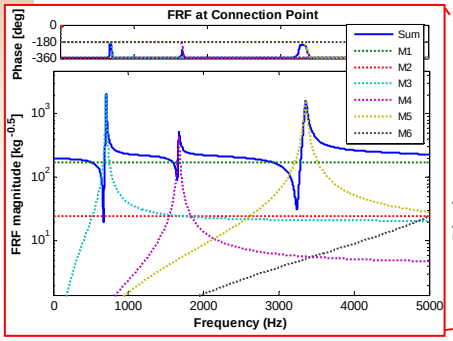
Experimental Substructuring CHALLENGES

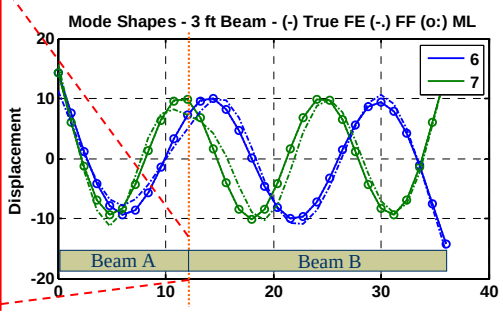
- Approach is limited to motions that can be measured accurately.
  - Free-free boundary conditions:
    - Easy to reproduce experimentally
    - Poor accuracy (slow convergence)
    - Can be augmented with attachment modes (residual flexibility)
  - Fixed interface modes
    - More efficient for rigidly connected substructures
    - Difficult or impossible to realize experimentally
    - Must be supplemented with constraint modes which are even more challenging to measure!
- Measurements are subject to noise / errors.
  - How do we design tests to reduce errors?
  - Can an adequate model be created in the presence of inevitable measurement errors?
  - Substructure models require the rotation at the connection point, which is challenging to measure reliably!



Inter-relationships between FBS and MS

- Discussion so far focused on Modal Substructuring
- Frequency Based Substructuring:
  - An alternative where the Frequency Response Functions (FRFs) of each component are combined to predict the FRFs of the assembly.
- These have different advantages and disadvantages and give different yet complimentary views on the accuracy required!





Mathematics Notation used in this Short Course

- This course uses the following mathematical notation (as much as possible) although some deviations will be necessary:
  - Scalar variables italic: $x, y, z, \ldots$
  - Vectors and matrices bold upright: $\mathbf{x}, \mathbf{y}, \mathbf{M}, \mathbf{K}, \ldots$
  - When possible lower case for time-varying vectors and upper case for vectors that are functions of frequency: $\mathrm{x}(t), \mathrm{X}(\omega)$
- **Our goal is for you to learn and gain new skills. Please feel free to ask questions at any time!**

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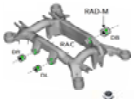

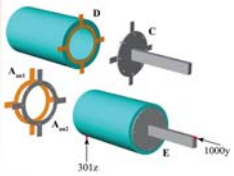

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